SUBSTRATE DICING METHOD

Cross-Reference to Related Applications

[0001] This application is a continuation of co-pending U.S. Serial No. 10/075,109 filed on February 13, 2002 which isa continuation of U.S. Serial No. 09/645,917 filed on August 25, 2000 and now issued as U.S. Patent No. 6,354,909 which is a continuation of U.S. Serial No. 09/358,046 filed on July 21, 1999 and now issued as U.S. Patent No. 6,152,803, which is a continuation-in-part of U.S. Serial No. 09/022,619 filed on February 12, 1998 and now issued as U.S. Patent No. 5,934,973, the disclosure of which are hereby incorporated by reference in their entirety.

Field of the Invention

[0002]The invention relates generally to the dicing ofsemiconductor wafers and, more particularly to the monitoring of blade location and flange clearance for safely cutting a semiconductor wafer.

Background of the Invention

[0003] Die separation, or dicing, by sawing is the process of cutting a microelectronic substrate into its individual circuit die with a rotating circular abrasive saw blade. This process has proven to be the most efficient and economical method in use today. It provides versatility in selection of depth and width (kerf) of cut, as well as selection of surface finish, and can be used to saw either partially or completely through a wafer or substrate.

[0004] Wafer dicing technology has progressed rapidly, and dicing is now a mandatory procedure in most front-end semiconductor packaging operations. It is used extensively for separation of die on silicon integrated circuit wafers. Increasing use of microelectronic technology in microwave and hybrid circuits, memories, computers, defense and medical electronics has created an array of new and difficult problems for the industry. More expensive and exotic

materials, such as sapphire, garnet, alumina, ceramic, glass, quartz, ferrite, and other hard, brittle substrates, are being used. They are often combined to produce multiple layers of dissimilar materials, thus adding further to the dicing problems. The high cost of these substrates, together with the value of the circuits fabricated on them, makes it difficult to accept anything less than high yield at the die-separation phase.

[0005] Dicing semiconductor wafers by sawing is an abrasive machining process similar to grinding and cutoff operations that have been in use for decades. However, the size of the dicing blades used for die separation makes the process unique. Typically, the blade thickness ranges from 0.6 mils to 500 mils, and diamond particles (the hardest well known material) are used as the abrasive material ingredient. Because of the diamond dicing blade's extreme fineness, compliance with a strict set of parameters is imperative, and even the slightest deviation from the norm could result in complete failure.

[0006] The diamond blade is a cutting tool in which each exposed diamond particle comprises a small cutting edge. Various dicing blades are available commercially. By way of example, a sintered diamond blade includes diamond particles which are fused into a soft metal such as brass or copper, or incorporated by means of a powdered metallurgical process; a plated diamond blade includes diamond particles which are held in a nickel bond produced by an electroplating process; and a resinoid diamond blade is one in which diamond particles are typically held in a resin bond to create a homogeneous matrix. Silicon wafer dicing typically uses the plated diamond blade, which has proven to be most successful for this application.

[0007] Because most state-of-the-art dicing equipment has been designed specifically to dice silicon wafers, problems arise when it is necessary to cut harder and/or more brittle materials. Blade speed and torque, depth of cut, feed rate, and other performance parameters have been optimized for silicon. However, hard and brittle materials require different blades and equipment operating parameters, the proper selection of which is a key to success for

high-yield dicing. In any cutting operation, tool sharpness is of primary importance. More exactly, it is necessary that the cutting tool maintain its sharpness throughout the cutting operation. When cutting hard material such as sapphire or garnet, the cutting edges become dull quite rapidly. Because the dulled cutting edges cannot be re-sharpened in the usual manner, it is desirable that they be pulled loose from the blade, or else be fractured to expose new sharp cutting edges.

[0008] An important characteristic of the resinoid diamond blade that promotes effective cutting is its self-sharpening ability. The blade requires no dressing at all, in contrast to most metal-bonded (sintered or electroplated) diamond blades. Sharpening is accomplished automaticallyby the cutting process. As a cutting edge becomes dull, it experiences increased cutting forces that eventually either pull the diamond particle loose from the blade or else fracture it to produce a new sharp cutting edge. A diamond blade that does not exhibit this property cannot properly cut hard materials, nor can it perform properly if saw operating parameters interfere with the self-sharpening mechanism.

[0009] By way of example, U.S. Patent No. 4,219,004 addresses a problem in the art of getting the blade cutting surface perpendicular to the substrate being cut and discloses blade mounting means comprising a pair of generally flat round collars, flanges, having a round central opening for receipt by the saw spindle. Further, the outer diameters of the collars are less than the blade diameter for providing an exposure of approximately 15 mils. A blade exposure not greater than 20 to 25 times the blade thickness is recommended. Replacing the collars with those having smaller diameter are disclosed for providing desired exposure and for replacing collars as the blade wears and exposure is reduced. Methods for monitoring or measuring the exposure during the dicing of the substrate is not addressed. U.S. Patent 4,787,362 discloses an abrasive cutting blade having very high rigidity useful in dicing silicon wafers and hard materials. The use of the flange or spacer for maintaining blade rigidity and providing blade exposure sufficient for

completely penetrating the work piece and cutting partially into the intermediate carrier typically used is disclosed. Wobble or run-out is of concern and is inversely proportional to the blade exposure. As a result, blade exposure is held to tight and typically minimal dimensions. A rigid blade core is described for preventing run-out from causing the core to make contact with the workpiece and causing widening of the cut and a less than even cut. Making the flange larger for providing less exposure is not addressed. However, less exposure means greater chance for inadequate cooling and greater chance of the flange hitting the work piece. There remains a need to effectively and economically resolve these problems. U.S. Patent No. 3,987,670 discloses a displacement transducer manually applied to a diamond blade cutting surface for measuring a distance from the blade cutting edge to a fixed reference distance on the blade. The transducer is mounted on a portable fixture. Blade wear of diamond blades generally in the range of 18 to 36 inches are addressed and the problems associated with measuring blade wear of these blades are identified. The transducer is provided with suitable readout devices to determine blade wear. Although blade wear is addressed, it is for relatively large, easily visible blade sizes, and measued while the blade is held motionless. Further, the issues associated with exposure and depth of cut into a substrate is not addressed. Flange clearance is not a major concern for 18" to 36" blades.

[0010]There is a need to monitor blade exposure, the amountof blade extending from the flanges holding the blade therebetween, during a wafer or substrate dicing for maintaining sufficient clearance between the flange edges and the substrate to provide adequate cooling, and further for preventing the flanges from contacting the substrate, often containing electronic chips valued in the many thousands of dollars. There is further a need to monitor and control the location of the cutting blade with respect to the location of the wafer to be cut and to efficiently and effectively control positions prior to a first cut and during movement of the wafer on its table for subsequent cuts. By way of example, a dicing machine user will typically try to mount the wafer at the

center of the table or chuck holding the wafer during the cutting operation. In the alternative, computer aided chuck and saw movement will determine measured cuts from the table center and move the dicing saw relative to the center coordinates, sometimes actually moving the table to the center prior to moving it to the appropriate cutting location. This adds expensive operating time, especially when one considers that thousands of cuts may be required within one wafer dicing project. When a cut is to be made close to an edge of the wafer, and the blade is allowed to make a cut close to the wafer edge, the blade may ripe off a section of the wafer, which can require disposal of the entire wafer, or extensive attempts and time for salvaging what is typically a very expensive wafer including multiple electronic elements.

[0011]Various approaches have been used to identify a locations of a workpiece in computer aided machines. By way of example, U.S. patent No. 4,233,625 to Altman discloses the use of television monitoring for aligning successive configurations of semiconductors. U.S. patent No. 5,422,579 to Yamaguchi discloses the use of a camera for identifying probe positions on a card and recognizing reference probes for providing a corrective movement to a work table. U.S. Patent No. 4,819,167 to Cheng etal. discloses a system and method for determining the location of a semiconductor wafer relative to its destination position using an array of optical sensors positioned along an axis transverse the path of movement of the wafer. Trigger points providedby the sensor array as the wafer is moved, provide locus information data to a processor for calculating the center of the wafer. U.S. Patent No. 3,670,153 to Rempert et al. discloses the use of a light sensing element and scanning of the object for detecting dark and light regions in determining edges of the object to be measured. In spite of the many computerized optical devices and configurations, there still remains a need to economically provide a method for effectively and efficiently locating the position of the wafer on the work table for optimizing movement of the table or workpiece during sawing operations and for providing a safe location at which the saw can operate without damage to the wafer and saw, or hazard to the saw and operator.

Summary of the Invention

[0012] In view of the foregoing background, it is therefore an object of the present invention to provide a method for safely and efficiently dicing a semiconductor wafer or substrate by moving the table relative to the saw based of a location of the wafer, while preventing the blade flange from contacting the substrate. It is further an object of the invention to prevent the cutting of a substrate so close to its edge that it may shatter the substrate or damage the blade. It is yet another object of the invention to monitor flange clearance during the cutting of the wafer for cutting the wafer without having the flange contact the wafer as a result of blade wear. It is yet another object of the invention to provide automation to the traditionally manual and semiautomatic monitoring of the wafer dicing process.

[0013] These and other objects, features, and advantages of the invention, are provided by a method for dicing a substrate using a programmable dicing saw. The dicing saw includes a processor operable for movement of a spindle carrying a dicing blade and a work surface upon which the substrate is removably secured. Movement of the dicing blade toward and away from the work surface is controlled by movements within an orthogonal coordinate system having its center at a center location of the work surface. The dicing blade is mounted onto the dicing saw spindle juxtaposed between a flange pair for rotation of the dicing blade about a spindle axis. The dicing blade has an outer diameter defining a cutting edge and is greater than each flange diameter of the flange pair for providing a blade exposure for cutting into a substrate. Preferably, the substrate to be cut is removably securing onto the work surface and within a blade path of the dicing blade.

[0014] Locating the center of the substrate provides for an efficient movement of the blade relative to the center and save time when compared to attempts to manually center the substrate and move the blade during the cutting process

relative to the center of the work surface rather than the center of the substrate. A preferred method of locating the center of the blade includes the steps of aligning the dicing blade with a first edge of the substrate for determining a substrate first edge location on the work surface, aligning the dicing blade with a second edge of the substrate for determining a substrate second edge location on the work surface, wherein the first edge laterally opposes the second edge and the rotationalaxis of the dicing blade is perpendicular to the blade paths along the first and second edges, rotating the substrate ninety degrees about an axis perpendicular thereto, aligning the dicing blade with a third edge of the rotated substrate for determining a substrate third edge location on the work surface, wherein the blade path along the third edge is perpendicular to the blade path along the first edge, and aligning the dicing blade with a fourth edge of the substrate for determining a substrate fourth edge location on the work surface, wherein the third edge laterally opposes the fourth edge. Edge data representative of the measured substrate first, second, third, and fourth edge locations is entered into the processor operable with the dicing saw for determining the center of the substrate and calculating a distance between the center of the substrate and the center of the work surface for providing a compensating command to the programmable dicing saw. Movement of the substrate is then made relative to the center of the substrate. If desired, the dicing saw is located over the center of the substrate when initiating blade and work surface movement. The spindle and work surface are moved relative to the center of the substrate for positioning the dicing blade based on the compensating command.

[0015] In a preferred operation of the dicing saw when cutting a substrate includes aligning the dicing blade for making a cut into the substrate along a first blade path, dicing the substrate along the first blade path and subsequent blade paths as desired. The blade outer diameter reduces with each cut into the substrate, thus reducing the blade exposure, and further reducing a clearance between the flange pair and a substrate top surface for each subsequent cut. Therefore, the flange clearance is determined and monitored

by measuring the blade exposure after a preselected number of cuts during the substrate dicing.

[0016] In one preferred method when aligning the blade for dicing along an edge of the substrate, the dicing blade is first aligned for travel parallel to and proximate the first edge of the substrate. An offset command is provided to the programmable dicing saw for laterally moving the blade toward the center of the substrate prior to making a cut into the substrate. The offset command is representative of a preselected offsetting displacement of the blade from the edge to avoid damage to the blade and substrate that typically results when the blade slides along the substrate edge rather than cutting into the substrate.

[0017] The present invention provides for accurately making arcuate cuts into the substrate. With such a method, the dicing blade aligning comprises first aligning the dicing blade for travel along a first blade path at a preselected distance from the center of the substrate for the dicing thereof. A desired cut is made into the substrate. Then the dicing blade is aligned for travel along a second blade path at the preselected distance from the center of the substrate for the dicing thereof, wherein the second blade path radially opposes the first blade path. A desired cut is then made. The substrate is rotated by a preselected arc and the aligning and dicing steps are repeated for providing multiple cuts within the substrate. The substrate rotating comprises incrementally rotating of the substrate a multiplicity of times sufficient for providing an arcuate cut to the substrate. With such a method, a circular shape can result.

[0018] To guard against damage to the substrate, the dicing method further comprises the step of automatically stopping the dicing of the substrate when the flange clearance is reduced to less than a preselected minimum clearance. A separation distance between the work surface and the blade cutting edge is calculated using the processor, and blade movement into the substrate is automatically stopped when the blade cutting edge is greater than a preselected separation distance. In one embodiment, the flange clearance is

calculated by sensing the blade cutting edge during blade rotation and prior to the substrate cutting step for setting a reference position for the blade edge and spindle axis, and sensing the blade cutting edge after the preselected number of cuts for determining an axis position difference for the worn blade. The difference is used to update data input to the processor regarding the reduction in blade diameter, the blade exposure, and thus the step of determining the flange clearance. The blade exposure measurement is made at preselected intervals throughout the substrate dicing steps. The flange clearance is automatically calculated at preselected intervals throughout the substrate cutting. A minimum flange clearance is preselected for continuing the dicing. The minimum flange clearance should provide effectivecoolant flow to the blade, adequate blade rigidity and thus a squareness of cut, and an acceptable blade chipping. Calculating blade exposure includes measuring blade wear after a preselected number of cuts for automatically monitoring the exposure during the dicing step and providing a first stop movement signal to the processor when a minimum exposure results in a minimum flange clearance for the dicing steps. Calculating a separation distance between the work surface and the blade cutting edge is madeand provides a second stop movement signal to the processor when a preselected maximum separation distance is measured, thus indicating blade wear. Movement of the dicing blade toward the work surface is automatically stopped when any stop movement signal is received. The exposure calculating step comprises the sensing of the blade edge during blade rotation prior to the dicing of the substrate for setting a reference position for the blade edge and spindle axis, and sensing the blade edge after the preselected number of cuts for determining an axis position difference for the worn blade. The exposure calculating step is made by the processor using the axis position difference and the flange diameter.

Bri f D cription of th Drawings

[0019]A preferred embodiment of the invention as well as alternate embodiments are described by way of example with reference to the accompanying drawings in which:

[0020]FIG. 1 is a partial diagrammatic side view of a dicing saw embodiment of the present invention;

[0021]FIG. 2 is a partial end view of a dicing blade held onto a spindle within flanges;

[0022]FIG. 3a and 3b are plan and end views, respectively, of a dicing saw blade;

[0023]FIG. 4 is a partial diagrammatical elevation view of a wafer cutting arrangement;

[0024]FIG. 5 is a functional block diagram of the system control used in one preferred embodiment of the present invention;

[0025]FIG. 6 is a partial cross-sectional view of a height sensor;

[0026]FIG. 7 is a flow diagram illustrating a logic of the dicing saw system of the present invention;

[0027]FIGS. 8a, 8b, and 8c are diagrammatical plan views of a substrate illustrating aligning and dicing thereof;

[0028]FIG. 9 is a perspective view of one preferred embodiment of a dicing saw operable with the present invention;

[0029]FIG. 10 is a partial diagrammatical plan view illustrating an offset blade path; and

[0030]FIG. 11 is a diagrammatical plan view illustrating a circular cutting of a substrate in accordance with the present invention.

Detailed Description of the Preferred Embodiments

[0031]The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set

forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

[0032] The preferred embodiment of the present invention is described with reference to the drawings, wherein a method and system **10** for automatically dicing a semiconductor wafer or a substrate **12**, herein described by way of example, provides a safe clearance **14** between a dicing blade flange **16** and the substrate **12**, as illustrated with reference to FIG. 1. By way of example, a resin-bonded dicing blade **18** will wear or reduce in diameter **20** as it is used to cut various substrate materials. The blade **18** is mounted on a spindle **22**, as illustrated with reference to FIG. 2, for rotation about a spindle axis **24**. The flange **16** is typically a flange pair **17** holding the blade **18** between the flange pair **17**. The dicing blade **18** has its diameter **20**, an outer diameter, defining a cutting edge **26**. The blade outer diameter **20** is greater than the diameter of each flange **16** thus providing a blade portion **28** extending radially outward from the flange pair **17** for providing this portion **28** as the blade exposure.

[0033] Depending on the hardness, density and abrasiveness of the blade material, as well as the cutting rates, spindle rotation speeds, and ability to cool the blade **18** while it is cutting, varying amounts of blade wear will be realized, thus reducing the blade exposure **28**. The blade wear is further complicated by the type or make-up of the diamond blade **18** itself. Fine abrasive blades are more difficult to cool than blades having larger abrasives. A typical dicing blade **18** is further illustrated with reference to FIGS. 3a and 3b identifying a blade width **30** and blade inner diameter **32** as well as the outer diameter **20** defining the blade cutting edge **26**.

[0034] Dicing blades **18** are typically fragile. They may be metal or resin in make-up, and are typically have widths **30** ranging from as thin as .00012" to .500". Outer diameters **20** vary from as little as 1" to 6". Due to the fragile nature of the dicing blade **18**, they require stiff flanges **16** for mounting them onto the rotating spindle **22**. Flanges **16** are typically made from metals such as aluminum, stainless steel or titanium. Flanges **16** for holding the dicing

blade **18** come in an infinite range of diameters, each smaller to some degree than the dicing blade **18** as earlier described. The difference between the flange radius and blade radius is the blade exposure **28**. It is the flange pair **17** and small blade exposure **28** extending therefrom, that gives the extremely thin dicing blade **18** a stiffness sufficient for cutting into the substrate **12**.

[0035] With reference again to FIG. 1, the substrate **12** having a substrate thickness **34** is held onto a work surface **36** of the dicing saw. Typical work surfaces or dicing saw chucks, as they are also known, hold a workpiece, such as the substrate **12**, using a vacuum. In many arrangements, as illustrated by way of example, with reference to FIG. 1, a carrier **38** is placed on the work surface **36** for receiving the substrate **12**. Such an arrangement permits the blade **18** to cut completely through the substrate **12** without cutting into the work surface **36**.

[0036] By way of further example, and with reference to FIG. 4, it is preferred that the blade exposure **28** be about ten times the blade width **30**. For example, a .002" thick blade would be exposed .020" as a rule of thumb. Application know-how by those skilled in the art will allow flexibility of adherence to this rule. In addition, there is a minimum or safe flange clearance **14** between a flange edge **40** and a substrate top surface **42**. The flange clearance **14** must be sufficient for permitting coolant from a coolant nozzle **44**, as illustrated with reference again to FIG. 1, to provide adequate cooling during the dicing process. Further, the flange clearance **14** must be monitored and a minimum clearance not exceeded in order to avoid contact between the flange edge **40** and the substrate top surface **42** which will result in damage to a typically expensive semiconductor wafer or substrate **12**. With reference again to FIG. 4, and continuing with a dimensional example, cutting the substrate **12** having a thickness of .010" and wanting to cut through the substrate and beyond by .002", the depth of cut **46** would be .012". This would result in a flange clearance **14** of .008". As the dicing blade **18** wears, reducing the length of its outer diameter **20**, and the dicing saw is programmed to automatically maintain the depth of cut **46**, or a dicing saw operator

manually lowers the blade **18**, the flange clearance **14** is reduced. If such lowering continues, the flange **16** will collide with the substrate **12** resulting in damage to the substrate **12**, the blade **18**, and possibly cause injury to the operator. As a result, tracking the flange clearance **14** is an essential step for providing operator and product safety.

[0037] If one considers the flange clearance **14** at a dimension as small as .008", by way of example, and the that the operator cannot distinguish between clearances **14** of .008" and .000", it is apparent that the need exists to track such minute clearances automatically. Typically, a 5 mil flange clearance **14** is desired. An operator would have to see 3 mils of wear. When one adds coolant and blade shields (not shown) to protect the operator, the extreme difficulty in seeing the flange clearance **14** is further realized. Manually tracking blade wear and calculating any resulting reduction in flange clearance **14** becomes an impractical and inadequate method resulting in an untrustworthy operation for the dicing of expensive semiconductor substrates **12**.

[0038] With reference again to FIG. 4, it is clear that in addition to monitoring the flange clearance **14** and depth of cut **46**, a separation distance **48** between the blade cutting edge **26** and work surface **36** can also be determined. Further, a depth of cut **50** into the carrier **38** can also be monitored.

[0039] With reference again to FIG. 1, in one preferred embodiment of the present invention, a height sensor **52** is rigidly affixed to the dicing saw **54** with the work surface **36** and are moveable together. In this way, a sensing surface **56** of the height sensor **52** provides an accurate reference position **58**. With such a reference position **58** for the sensing surface **56**, the height positions of the work surface **36**, the blade cutting edge **26**, the substrate top surface **42**, a carrier top surface **60** are measurable and their relative elevations located. The position of the spindle axis **24** is controllable for movement of the axis **24** for causing the cutting edge **26** of the blade **18** to make contact with the sensing surface **56** wherein the height sensor **52** provides a signal representative of the position of the blade cutting edge **26**,

relative to an initial position established prior to the cutting process. In one embodiment of the saw **54**, the work surface **36** and sensor **52** move to position the sensor **52** and substrate **12** for the operation of the saw **54**. As schematically illustrated with reference to FIG. 5, a sensing signal **62** is delivered to a processor **64** for calculating blade wear, the blade exposure **28**, and thus the flange clearance **14** having data representative of the substrate thickness **34**, carrier thickness **64** and surface locations as earlier described. The processor **64** calculates the flange clearance **14** by measuring the blade wear after a preselected number of cuts into the substrate **12** for automatically monitoring the exposure **28** and thus the flange clearance **14** during the dicing of the substrate **12**. In typical operation, the dicing blade **18** makes multiple cuts through the substrate **12** for separating the substrate into individual chips or die (not shown), makes cuts into a blank substrate, or shapes a substrate as desired. By repeating the sensing of the blade cutting edge **26** through the movement of the spindle axis **24** toward the sensing surface **56** for contacting the sensing surface **56** with the blade cutting edge **26**, the flange clearance **14**, which is reduced as the blade **18** wears, is monitored during dicing or cutting of the substrate **12**. The flange clearance **14** is calculated by the processor **64** using updated blade exposure **28**, position of blade edge **26** above the work surface **36**, the substrate thickness **34** and a diameter for the flange **16** selected. The processor **64** is programmable for controlling spindle movement **66** and for storing **68** and displaying **70** the input and monitored data.

[0040] With the data storage **68**, a blade history is automatically tracked; with such history, displays blade wear information to the operator as well as total wear of the blade **18** using display **70**. Such history is then used for determining the control of the spindle axis **24** for making height sensing movements. Efficiency is thus increased by making such height sensing movements when necessary based on the blade history for the blade **18** having a known composition. Empirical data rather than judgment is then relied upon for setting the control parameters for the dicing saw.

[0041]As illustrated by way of example with reference to FIG. 6, the height sensor **52** used in the embodiment herein described, comprises a sensor provided by European Semiconductor Equipment Center (ESEC), employing a flexible membrane **72** moveable when the sensing surface **56** is contacted. A ceramic member **74** is attached between the flexible membrane**72** and a piezo-electric crystal **76**. Movement of the crystal**76** causes the signal **62**, representative of the movement. The blade**18** makes contact with the sensing surface **56** while rotating and thus causes wear or cutting of the sensing surface **56**. Such cutting or wear causes excessive vibration and damage to the piezo-electric crystal **76**. Replacement of the height sensor**52** or components such as the flexible membrane **72** are impractical and often times expensive. An improvement to the height sensor is made by attaching a disk **78** to the sensing surface**56**. The disk **78** is replaceable and protects the sensing surface**56**. The disk**78** is preferably made of a hard material that will resist cutting by the dicing blade**18**, or if damaged, easily and inexpensively replaced. In a preferred embodiment of the present invention, the disk**78** is magnetically attached to the sensing surface**56**. Alternate adhesion methods, such as gluing, are acceptable. In one embodiment, the disk**78** is made from carbon steel. The carbon steel disk**78** is first nickel-coated for preventing the steel from rusting due to exposure from the coolant, and provided with a second coating of diamonds and chrome for providing hardness and resisting damage by the rotating blade**18**. In an alternate embodiment, the disk**78** comprises a magnetic ceramic material.

[0042]In operation, and as illustrated with reference again to FIGS. 1 and 2, the blade **18** is mounted on the spindle **22** between the flange pair**17** for providing the blade exposure**28**. The substrate **12** to be cut is mounted on the work surface**36** as earlier described, and as illustrated in the flow diagram of FIG. 7 as numeral**80**. The blade **18** is rotated about the spindle axis **24** as is typical for dicing saws, and the substrate**12** is cut or diced as desired. The substrate dicing **82** continues for a preselected number of cuts. When the number of cuts reaches the preselected number, or exceeds a maximum

specified **84**, the blade edge **26** is delivered to the sensing surface **56** for making a height measurement **86**. Blade exposure is calculated for determining the flange clearance **14** and the separation distance **48**, as earlier described, is also calculated **88**. The calculated flange clearance is compared to a minimum allowable clearance **90**, and the separation distance **48** is compared **92** to a preselected distance. If the flange clearance **14** or the separation distance **48** do not meet that required, dicing saw operation is stopped **94** until corrective action is taken. If the dicing saw is operating within the standards set for flange clearance and separation, substrate dicing continues **96**.

[0043]With reference now to FIG. 8a, it is typical for an operator of the dicing saw to attempt to mount the substrate **12** at the center **100** of the dicing saw chuck or work surface **36**, as has been herein described, by way of example. However, there have always been errors in attempting a precise placement of the substrate **12**. The present invention provides for the automatic transfer of a "home position" at the center **100** of the work surface **36** to the center **102** of the substrate **12**, and uses the dicing saw processor **64** to compensate for placement of the substrate at other than work surface center **100**. The present invention provides for the determination of the center **102** of the substrate **12** and its distance away from the center` **100** of the work surface **36** by aligning of the dicing blade **18** at edges of the substrate **12** and entry of the edge locations into the processor **64**.

[0044]As illustrated with reference again to FIG. 8a, determining the center **100** of the substrate **12** preferably comprises the step of first aligning the dicing blade **18t** with a top edge **104** of the substrate **12** for determining a substrate top edge coordinate location **106** on the work surface **36** relative to the center **100** of the work surface. The location is entered into the processor **64**. By way of example, reference is made to top and bottom edges as the edges would typically appear to the operator as the operator faces the work surface from in front of the dicing saw **54**. Likewise, relative terms as first, second, and the like can also be used. Next, the dicing blade **18b** is aligned

with the bottom edge **108** of the substrate **12** for determining a substrate bottom edge location **110** on the work surface **36**. The top edge **104** laterally opposes the bottom edge **110** and the rotational axis **24** of the dicing blade **18** is perpendicular to the blade paths **112**, **114** respectively, along the top and bottom edges. Also, it is preferred that the same edge of the blade **18** be used when aligning the blade with the edges, the top edge of the blade **18** is illustrated herein by way of example. Further, the substrate **12** herein described by way of example has a rectangular shape. The present process is applicable to arcuate shaped substrates as well, in which case the blade **18** would be aligned generally tangent to the arcuate edge. Likewise, and as illustrated with reference to FIG. 8c, the substrate **12** may be placed on the work surface **36** at other than parallel to the blade path **112**. In such a case, the blade would be preferably aligned with edges closest to the center of the substrate.

[0045] After alignment and data entry of the top and bottom edges **104**, **108**, the substrate is rotated by rotating the work surface ninety degrees, as illustrated with reference to FIG. 8b. The dicing blade **18t** is aligned with a third edge, now viewed as a rotated top edge **116** of the rotated substrate **12** for determining a substrate rotated top edge location **120** on the work surface **36**, wherein the blade path **112** along the rotated top edge **116** is perpendicular to the blade path along the earlier measured top edge **104**. The dicing blade **18b** is then aligned with the rotated bottom edge **118** for determining a substrate rotated bottom edge location **122** on the work surface, wherein the rotated top edge laterally opposes the rotated bottom edge. Rotated top and bottom edge locations **120**, **122** are entered into the processor **64** for calculation of the center **102** of the substrate **12** and its location relative to the center **100** of the work surface **36**. By determining a distance between the center of the substrate and the center of the work surface for providing a compensating command **124** to the processor **64**, as illustrated with reference again to FIG. 5, for movement of the work surface by

a controller **126**. The controller **126** is manually directed during the aligning steps through a control panel input **128**.

[0046] As illustrated with reference to FIG. 9, such alignment preferably includes the use of a camera **130** focused onto the substrate **12** and a video monitor **132** for viewing the substrate image **134** and blade path images which is indicated by cross hairs **136** provided for viewing by the video monitor **132**. A data monitor **138**, a keyboard **140**, and joysticks **142** are provided for data input and processor output viewing. The process of lining up the top edge the blade **18** with the substrate **12** far edges preferably includes using the joystick and optics illustrated with reference to FIG. As described, the video monitor **132** displays the blade path as well as the substrate, and thus allows the operator to match up the entities by moving the joysticks **142** on the control panel **128**. In a preferred operation, the work surface is at a rotation angle of zero degrees within an X-Y plane of the work surface. This zero degree rotation angle is approximate and should be fairly close for a rectangle substrate, but is not critical for a round or circular substrate. In one peferred embodiment of the system **10**, a dialog box **144** on the data monitor **138** is viewed by the operator. Commands for the processor are viewed and the operator enters and views the particular commands such as the aligning steps earlier described. Further, and by way of example, in one programmed process, the work surface is automatically rotated after entry of the second alignment step. The workpiece is rotated 90 degrees and shown in its new orientation within the dialog box **144** on the data monitor **138**.

[0047] Generally, the operator completes the alignment steps and with each step provides a data entry to the processor. For each step, the operator is guided by the processor through the dialog box display which will include a status as well as instructions for the process being completed. After sufficient data has been entered for a particular calculation, such as the determination of substrate center, the processor displays the substrate center coordinates, which coordinates are used to efficiently move thework surface during

operation of the dicing saw for making multiple cuts into the substrate, as earlier described.

[0048]It is often desirable to make cuts in a blank substrate for reshaping the substrate or providing special cuts, whether rectangular or arcuate in shape. To avoid making a cut so close to the edge, top edge**104** by way of example with reference to FIG. 10, of the substrate**12** so as to damage the blade having blade width **30** or break apart the substrate, an offset command**146** is entered into the processor **64**, as illustrated with reference again to FIG. 5, to allow the processor to automatically relocate the blade path**112** prior to cutting the blank substrate **12**. The offset alignment process allows the operator to make a multiple offsets, and withthe aid of the optics and joysticks earlier described, can adjust and select the applicable blade path**112** for the particular cut of interest.

[0049]Generally, the offset alignment will be made for all desirable sides of the substrate before the dicing begins. The automatic adjustment or offset alignment for the preselected edges are made just before the side is cut. An offset dimension will generally range from zero to a few millimeters. An offset will also be used when a blank substrate or wafer having a circuit pattern removed from its edges is to be cut. In other words there are no streets with discrete die formations on the substrate, by way of example.

[0050]As illustrated, by way of example, with reference again to FIG. 10, the operator lines up the top edge **104** of the substrate **12** for displacement **148** of the cut at a distance into the substrate toward the center**102** of the substrate. An offset dimension representative of the displacement**148** is entered into the processor, and will typically only be activated on the first cut line for a given side. To initiate the offset process, the operator will align the cross hairs**136**, earlier described with reference to FIG. 9, using the optics joysticks**142** to set the edge location **106** of the substrate. The offsetwill be calculated from this aligned location **106**. When desired, a flange alignment is also implemented with respect to the center of the substrate.

[0051]By way of further example of the unique capability provided to the dicing saw by the present inventive methods, the blank substrate **12** is cut into a circular shape substrate **150** or a circle may be cut therein, as illustrated with reference to FIG. 11. As earlier described with reference to FIGS. 8a and 8b, the present invention provides for accurately locatng the center **102** of the substrate. As a result, an arcuate cut can be made into the substrate by making a multiplicity of straight dicing styled cuts **152**. In a preferred method, the dicing blade aligning comprises first aligning the dicing blade for travel along a first blade path **154** at a preselected distance **155** from the center **102** of the substrate **12** for the dicing thereof. A desired cut is made into the substrate. Then the dicing blade is aligned for travel along a second blade path **156** at the preselected distance **155** from the center **102** of the substrate **12** for the dicing thereof, wherein the second blade path radially opposes the first blade path. A desired cut is then made. The substrate is rotated by a preselected arc **158** and the aligning and dicing steps are repeated for providing the multiple cuts **152** within the substrate. The substrate rotating comprises incrementally rotating of the substrate a multiplicity of times sufficient for providing an arcuate cut to the substrate. With such a method, the circular shaped substrate **150** can result. The accuracy or tolerance within which a circle can be cut will depend on the preselected number of multiple straight cuts **152**, generally governed by the specific use of the substrate an the practicality of making a large number of cuts. One measurement of tolerance includes the difference in the length of a radius **160** for a circle **162** inscribed tangent to and excluding the multi-sided arcuate shape **150** and a radius **164** of a circle **166** inscribed tangent to and including the multi-sided shape. This tolerance is illustrated with numeral **168** in FIG. 11, by way of example.

[0052]Some important guidelines that should be considered in the selection of equipment intended for dicing hard, brittle materials include those related to feed rate or work surface movement, spindle rotational speed, blade use, and depth of cut. The range of feed rates available is important, and should be

compatible with the intended applications. Beware of machines that cannot achieve the low range of feed rates, and those that produce uneven table movement when set to low feed rates. The spindle rotational speed (rpm) is preferably variable, and preferably from about 5,000 to 40,000 rpm for a nominal two through five inch diameter blade. The method of accomplishing spindle speed changes is important, and the machine should provide operator indication of the selected spindle speed. The dicing saw should be capable of accepting hub-type or free-standing diamond blades in conjunction with adjustable coolant nozzles **44** and microscope alignment to accommodate any design differences. A machine that limits the user to a single type or source of diamond blade **12** should not even be considered. When considering the selection of a dicing saw, the maximum attainable depth of cut **46** should be ascertained, so that optimum blade utilization can be realized. This is a particularly important consideration for cutting thick substrates or substrates **12** as described herein.

[0053] We would all like to think that any cutting task could be successfully achieved by simply acquiring any machine and blade **18** combination, producing parts with virtually no loss of the substrate **12** or material being processed, and experiencing no edge damage to the finished parts or diced substrate. However, it has been shown that careful planning and control over the numerous variables is necessary in order to create such an efficient sawing system. Material type, depth of cut, desired throughput, feed rates, spindle speed, cooling nozzle design, mounting, kerf, blade exposure, diamond particle size, available power, and blade flange design, are but a partial list of the variable components affecting the sawing process. There are three critical laws or constraints for dicing and diamond grinding technology that should be followed. Applying these laws properly is critical in the proper selection of process components.

[0054] The parameters of rigidity, power, and cooling must be considered for each system component selection. It must also be understood that each component involved in the dicing or cutting process cannot create sawing

efficiency alone, but rather all of the components as an interactive system must be compatible in meeting standards. If just one component is in error, it could render all other properly selected components ineffective due to its dominance in the sawing process. Whether dicing thin silicon materials at inch-per-second feed rates, or cutting into heavy cross-sections of ceramic-based materially, system rigidity plays a major role in sawing efficiency. It is most important to note that rigidity not only pertains to the equipment being used, but also to the diamond blade **18** and workpiece or substrate **12** mounting methods, as well as to operating parameters. A rigidlymounted spindle **22** with virtually no end play or vibration is mandatory for dicing and diamond grinding. Additionally, the perpendicularity of the spindle axis**24** to the spindle direction of movement toward the work surface**36** is essential for the diamond blade **18** to run true. Presently, air-bearing spindles are the most commonly used because of their exceptionally smooth operation and extended working life.

[0055]While most end users will take considerable steps in assuring the rigidity of the machine they purchase, they will most often overlook the critical mounting requirements necessary for the diamond blade. No matter how well the diamond blade **18** was manufactured to run true, it can only run as accurately as the surfaces with which it comes into contact The bearing surfaces of the flanges **16** or spacers (not shown) must be flat, clean, and parallel. Spacers used in gang cutting operations are generally made from aluminum or titanium carbide, depending on the application. As described, the flanges **16** for single blade mounting are usually made from stainless steel. The flanges **16** will incorporate an undercut to reduce the bearing surface area in order to enhance intimate contact with the diamond blade. These surfaces, as well as the diamond blade surfaces, must be clean, with no loose particles present prior to assembly. This insures proper fitting of the mating surfaces. All flanges and spacers must be supplied with torque specifications to aid the user in preventing distortion and separation of thebearing surfaces from the diamond blade. The most frequent cause of blade breakage and oversize cut

widths, with relation to blade thickness **30**, is an improper flange torque or poor flange quality. Flanges **16** and spacers must be of high integrity in order not to induce vibration at operating spindle speeds.

[0056] The blade exposure **28** is a critical component within the variables affecting the overall rigidity of the sawing system. Over-exposure may cause wider than desired kerf, excessive edge chipping, non-squareness of cut, and blade breakage, while too little blade exposure can divert the critical coolant supply from the blade/material interface. The best results will be attained by adjusting the "ten times blade thickness" guideline or rule, earlier described, in accordance with a prerequisite that at least ⅓ to ½ of the diamond blade's exposure be buried into the cut. This prerequisite is the dominant variable in establishing proper blade exposure **28**. This approach offers improved stability at start, and depending upon material hardness and feed rates, can be fine-tuned with only minor adjustments. The tendency should be to expose the diamond blade **18** at a minimum to attain maximum blade rigidity, with caution given in regard to a possible coolant cut-off or a collision of the flange with the workpiece. The alternative is to run a maximum exposure within the guidelines, to reduce the amount of flange changes required in order to consume the entire working range of the self-sharpening diamond blade.

[0057] Equally important to rigid blade mounting procedures are the substrate mounting techniques. These two variables of the sawing system are the closest in proximity to the desired finished parts, and warrant proper attention. As earlier described, the substrate **12** is normally mounted on an intermediate carrier **38**, which is then mounted onto the work surface by vacuum or mechanical means. This enables the user to cut completely through the substrate without causing damage to the work surface **36**. Vacuum work surface chuck systems require a vacuum gauge to indicate holding stability and assure operating safety. The two most common intermediate carriers **38** are tape and glass. The substrate **12** is held to the "tacky" side of the tape, while wax is used as the holding medium for mounting on glass.

[0058] Effective cooling of the diamond blade at the point of contact with the material being processed is a basic essential for any diamond grinding application. The starting point for an efficient cooling system is the supply nozzle configuration **44** which directs the coolant medium. Dual nozzle **44** arrangements, illustrated with reference again to FIG. 2, are superior to single nozzle design in supplying coolant to the critical areas of the diamond blade during the cutting operation. Coolant must be directed at the blade/material interface as well as the leading edge of the blade. The coolant, after leaving this initial contact point, should follow along both sides and the extreme outside edge of the blade in such a manner that it will create intimate contact with these blade surfaces. A single nozzle will satisfy the directional requirement, but will fail to create intimate contact with the blade along its sides. The single stream of coolant, directed at the cutting interface, is split by the diamond blade into two separate streams and deflected away from the sides of the blade. The resulting decrease in cooling efficiency is noted by higher edge chipping damage when processing brittle materials, lower blade life, and erosion on the sides of the diamond blade, which will cause uneven cuts. Dual Nozzles provide two separate streams of coolant to the cutting interface, and at an angle to the cutting edge of the blade, so that each stream will favor one side of the diamond blade after providing the necessary coolant to the leading edge. This complement provides the necessary coolant to all of the critical areas of the cutting blade, with no loss of direction required for removing the debris generated during cutting. Coolant nozzles **44** must provide a full and airless flow of coolant. Additionally, the nozzles should be installed in close proximity to the blade in order to prevent excessive pressure drop of the supply, and to insure that no air will become entrapped in the coolant stream prior to contact with the blade/material interface. Recirculating coolant systems require efficient filtering to remove the particles generated during cutting. Coolant temperatures have a pronounced effect on blade life and cut quality in diamond grinding technology. Test results indicate that coolant temperatures above 80 degrees Fahrenheit should be avoided, while

temperatures of 50 degrees or less dramatically improve cutting performance. Refrigeration of the coolant medium is easily adapted to most recirculating systems, and is highly recommended.

[0059] While a specific embodiments of the invention have been described in detail herein above, it is to be understood that various modifications may be made from the specific details described herein without departing from the spirit and scope of the invention as set forth in the appended claims. Having now described the invention, the construction, the operation and use of preferred embodiments thereof, and the advantageous new and useful results obtained thereby, the new and useful constructions, methods of use and reasonable mechanical equivalents thereof obvious to those skilled in the art, are set forth in the appended claims.